

A PALEOMAGNETIC STUDY OF

THE CONCRETIONS

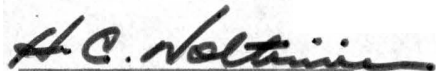
OF THE HURON SHALE

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by

Donald J. Cooke
The Ohio State University
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Approved by:



Advisor

Department of
Geology and Mineralogy

ABSTRACT

Samples from the Huron Shale (U. Devonian - Ohio) concretions are measured for remanent magnetism and anisotropy of magnetic susceptibility. Two magnetic components are found, a "soft" viscous component, and a "hard" post-depositional component carried by fine grained magnetite. The post-depositional stable remanence is perturbed by concretion growth which must therefore also be post-depositional. Growth of elongate pyrite crystals is noted in the concretions and in other pyrite bearing limestones, which may be related to the observed large deviation between the stable magnetic remanence of the concretions and the North American VGP for the Upper Devonian.

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INTRODUCTION

In order to study the geographic locations of the axial geocentric dipole through geologic time, researchers study the fossil magnetism of rocks. Most rock forming minerals are paramagnetic, but most rocks have weak ferrimagnetic properties caused by the presence of various ferri-magnetic iron oxides occurring as accessory minerals accounting for a few percent of the rock by weight (McElhinny, 1973). It is the magnetization of these accessory minerals which is termed rock magnetism, and the study of rock magnetism over geologic time scales is termed paleomagnetism (McElhinny, 1973).

The magnetization of a rock measured before any treatment (other than cutting a specimen to a suitable size) is termed natural remanent magnetization (NRM). The NRM of a rock may be acquired in several ways and the NRM usually contains several types of magnetization. There are five types of magnetization that are of primary importance in paleomagnetism.

Thermoremanent magnetization (TRM) is the magnetization acquired by a mineral when it is cooled through its unique Curie temperature in the ambient earth's field. Detrital remanent magnetization (DRM) is acquired by the deposition of magnetic grains in the ambient earth's field. Post-depositional remanent magnetization (PDRM) is caused by rotation of magnetic grains after deposition. Chemical remanent magnetization (CRM) is acquired during chemical changes in primary minerals below the Curie temperature. If any of these processes occurs in the presence of a magnetic field (i.e., the earth's) it can (but does not always) cause the acquisition of a magnetization in the rock parallel to that ambient field.

When a rock is placed in a field which is not parallel to the magnetic remanence, the magnetization of the smaller magnetic grains tend to align themselves over time toward the ambient field. Thus a rock can acquire a viscous remanent magnetization (VRM). This weak, but significant, component can usually be removed by alternating field (AF) demagnetization (see Methods).

If a stable component of magnetization can be experimentally established, a virtual geomagnetic pole (VGP) can be calculated for the specimen(s) studied. The virtual geomagnetic pole (VGP) is that geocentric dipole which would generate a field parallel to the stable magnetization of the specimen. If the stable magnetization of the rock is parallel to the earth's magnetic field at the time the rock was formed, the VGP is the apparent position of the geomagnetic pole. It takes the mean of a number of VGP positions to determine a valid paleomagnetic pole (McElhinny, 1973).

In order to examine the reliability of paleomagnetic data, Fisher (1953) devised a number of computations to define statistical parameters of a dispersion of data points on a sphere. Two of these parameters are used most often when discussing paleomagnetic data. The first parameter is the precision factor kappa (K) which defines the grouping of data. If the data are completely random, kappa is zero. If the data all fall on the same point, kappa is infinite. Generally, a kappa of 30 or greater is considered significant. The second parameter used is the cone of confidence (A_{95}). A_{95} is the cone in which the true mean lies at 95% confidence interval.

In addition to the determination of past paleomagnetic pole positions,

studies of magnetic properties can assist in drawing conclusions about the mineralogy and history of a rock. For example, during thermal demagnetization when siderite is heated above 500°C it converts to magnetite and a marked increase in magnetic remanence is observed (Strangway, 1969). Recent studies have indicated that anisotropy of magnetic susceptibility may be useful for determining paleocurrent directions by detecting long axis alignment of certain minerals (Rees, 1965).

In this study some of the magnetic properties of samples from the carbonate concretions of the Huron Shale are determined to see if:

1. A meaningful virtual geomagnetic pole (VGP) can be determined for the base of the Huron Shale.
2. Magnetic properties can be used to draw some conclusions about the origin of the concretions in relation to current models of formation.

DESCRIPTION AND COMPOSITION

The Devonian-Mississippian system in Ohio crops out in three widely separated areas (Fig. 1) and represents a transitional sequence between rocks of the Appalachian Geosyncline and those of the mid-continent cratonic area (Hoover, 1960). The sequence is predominated by highly argillaceous shales and siltstones. Figure (2) gives the stratigraphic relations worked out by Hoover (1960).

Samples used in this study are from the base of the Huron Member of the Ohio Shale. The Huron Shale is a grayish-black, fissile shale with quartz-illite chlorite mineralogy (Nelson, 1955). Clay mineralogy is mixed layer chlorite-illite (Criss, et al., 1973). In addition carbonized fossils of terrestrial plants are common (Criss, et al., 1973). Pyrite, kaolinite, and as much as 10% organic matter are present as minor constituents (Hoover, 1960). Carbonate minerals are not detectable except in areas adjacent to concretions (Criss, et al., 1973).

Significant numbers of carbonate concretions occur in the Olentangy Shale, and in the Huron Member of the Ohio Shale. Criss and others (1973) described three main types of Huron Shale concretions (Fig. 3). Samples used in this study are from concretions of the largest type.

Figure (4) is a photograph of one of the concretions sampled for this study. One of the most prominent features is the arching of the shale above and below the concretion. Figure (5) is a cross-section showing this arching. In addition, Figure (5) illustrates that bedding planes can be traced into the concretions (Stauffer, et al., 1911), and that the width between bedding planes increases towards the center (Westgate, 1926). These relations led to the different models of concretion growth.

Several models of origin have been proposed for the origin of the Huron Shale concretions. Newberry (1873) and Orton (1878) felt that the origin of the concretions was syngenetic (contemporaneous with enclosing rock) and that the shale arching was caused by differential compaction of the soft sediment around the solid concretion. Daly's study of concretions in equivalent shales in Canada (Daly, 1900) lead him to believe that the concretions were epigenetic (formed after enclosing rock). Stauffer and others (1911) and Wesgate (1926) agreed with Daly's contention of epigenetic origin of the concretions where shale deformation was caused by mechanical energy due to crystal growth.

Clifton (1957) reviewed current models, and using both field and laboratory techniques, developed a model of pene contemporaneous origin (post-depositional but pre-lithification) for Huron Shale concretions. In this model the concretion grows outward, incorporating shale, while compaction of adjacent sediments continues, thus explaining decrease in width between bedding planes. When concretion growth stopped, differential compaction would continue, causing the arching of the shale. Criss and others (1973), using geochemical techniques, developed a model for concretion growth from an adipocere (organic soap) precursor, where decomposition of proteinaceous matter would result in formation of adipocere from fatty acids reacting with calcium ions of the pore water. Adipocere would decompose to calcite, and dolomitization would occur later. Table (1) is their summary of the paragenesis of Huron Shale concretions.

Also, in the course of their study, Criss and others (1973) located a small, rotated Huron type concretion in a clastic dike in the Huron Shale near Milan, Ohio. Their interpretation of the field relations

confirms Clifton's penecontemporaneous model.

METHODS

Samples used in this study were collected 16 kilometers north of Worthington, Ohio, approximately 1,000 meters northeast of McKay Lodge which is operated by Northminster Presbyterian Church. Samples were taken as cores using a gasoline powered, water cooled, diamond drill similar to that used by Doell and Cox (1967a) and described in detail by Martin (1971). Cores were orientated in the field using a non-magnetic orientating tool, and a Brunton compass (Fig. 6). The magnetization of local features is assumed to be negligible. Care was taken in moving the saw and other magnetic objects far enough away so that they would not affect the accuracy of the Brunton. The 9 cores collected in this fashion were 2.5 cm in diameter and from 10-20 cm long. Several cores which could not be orientated were taken for thin and polished sections, which were prepared using standard petrographic techniques.

Samples were then taken to the OSU Paleomagnetism Laboratory, where they were sliced into 36 specimens, 2.5 cm long, using a water cooled, twin blade, diamond saw described by Martin (1971). Specimens were labelled indicating project (DC), concretion (0, 1, or 2), and core depth interval (1a first 2.5 cm, 1b second 2.5 cm, etc.), so that DC05 1b is the specimen covering the second 2.5 cm interval of the fifth core.

The natural remanent magnetization (NRM) of all specimens was then measured using a Schonstedt SSM 1-A spinner magnetometer using the six-spin technique described by Gough (1967), Doell and Cox (1967b), and Noltimier (1971a). NRM data for all specimens are given in Table (2).

A suite of 12 specimens from concretion (0) was systematically demagnetized using a Schonstedt GSD-1 alternating field (AF) demagnetizer. Specimens were demagnetized along 3 mutually perpendicular axes in a 400 Hz alternating field which decays at an exponential rate from a known peak field to near zero. Specimens were demagnetized in peak fields of 50, 100, 200, 300, 400, and 500 Oersteds (Zijderveld, 1967). Tables (3-8) give data for each AF treatment. Figure (7) is a plot of the normalized intensity (J/J_0) vs. peak alternating fields for each specimen and for the group mean, where J_0 = the NRM intensity of the specimen and J = the remanence intensity of the specimen after each demagnetization step.

A suite of 4 specimens was systematically thermally demagnetized, by heating and cooling in an a.c. electric furnace in a field free space maintained by a system of 2 meter Helmholtz coils (Parry, 1967; Stephenson, 1967). Specimens were treated from 100°C to 600°C at intervals of 100°C, and were then treated at 675°C. Tables (9-15) give data for the specimens at each temperature interval. Figure (8) is a plot of normalized intensities (J/J_0) vs. temperature for each specimen, and for the group mean. It should be noted that at 500°C specimen DC02 1a collapsed, apparently due to the decomposition of a pyrite layer, and was omitted from subsequent heatings. No change in residual intensity was observed in the other specimens due to the oxidation of pyrite to hematite, which occurs at 400°C, even though pyrite is a common mineral constituent of the concretions (Noltimier and Kopacz, 1976).

After AF demagnetization, 4 specimens were measured for anisotropy of magnetic susceptibility by B. B. Ellwood using an anisotropy torque meter (Ellwood, 1976), calibrated by the conducting loop method described by Noltimier (1971b).

Fisher statistics and virtual geomagnetic pole (VGP) positions were calculated and remanence directions were calculated and plotted using a FORTRAN computer program described by Smith (1976) and Watts (1975). Data reduction for anisotropy measurements was performed using a FORTRAN computer program written by B. B. Ellwood (1976), based in part on an earlier program in ALGOL written by Noltimier (1965).

RESULTS

The mineralogy, as determined from thin and polished sections, is more than 85% fine grained dolomite with minor amounts of quartz and pyrite. In addition, the mineral grains have a reddish brown stain which is probably colloidal hematite (George Moore pers. com.).

Extrapolation of the initial decrease in J/J_0 for the thermal demagnetization graph (Fig. 8) yields a Curie temperature for the primary magnetic mineral of 575°C . The AF demagnetization graph (Fig. 7) indicates that the primary magnetic mineral has a low coercive field, reaching $J/J_0 = 0.5$ by 400 Oe. These two observations are consistent for fine grained, single domain magnetite (McElhinny, 1973).

Figure (8) also shows a marked increase in remanence intensity above 500°C . this indicates the presence of significant amounts of siderite, converting to magnetite (Strangway et al., 1969). The thermal demagnetization results do not show an increase of residual magnetization at 400°C due to oxidation of pyrite (Noltimier and Kopacz, 1976).

The stratigraphic age attributed to the Huron Shale is Upper Devonian. Thus, the applicable pole position from McElhinney (1973) would be the Silurian-Devonian pole position for North America (29N, 123E).

This pole was determined from 7 VGP's determined by other authors and has an A_{95} of 11° and a kappa of 32.

The VGP position determined in this study, using samples demagnetized at 300 Oe is (11N, 155E). This VGP has a K of 61 and an A_{95} of 4° . Because A_{95} cones of confidence of the two pole positions do not intersect, the two poles are distinct (McElhinney, 1973). There are several possible explanations for the discrepancy:

1. An apparent polar wander path shift not previously recognized.
2. The stable magnetization found in this study is not primary and reflects a later secondary magnetization due to diagenesis.
3. The magnetization is depositional and has a DRM error of 22° in declination and 31° in inclination.
4. The magnetization of the rocks studied was controlled by something other than the earth's field at the time of acquisition.
5. The stable magnetization has two components which could not be differentiated on the basis of the demagnetizations performed.

The first explanation is unlikely, because of the 7 VGP's used to define the Silurian-Devonian pole stated in McElhinney (1973), 4 were from the Upper Devonian. The second explanation is rejected because the cone of confidence for the VGP determined in this study does not intersect the cone of confidence of any point on the post-Devonian North American polar wander path. The third explanation is unacceptable because there is no suitable mechanism for inclination or declination errors of this magnitude due to depositional effects (King and Rees, 1966).

In order to test the fourth hypothesis, 4 specimens were measured for anisotropy of magnetic susceptibility by B. B. Ellwood. The percent anisotropy was found by Dr. Ellwood to be 30% (Ellwood, pers. com.). Dr. Ellwood's interpretation is that the extreme anisotropy is due to

the radial growth of elongate pyrite crystals, and that this anisotropy in the paramagnetic pyrite may affect the remanence. This anisotropy is so extreme that it effectively overshadows any other fabric which may be present in the rock (Ellwood, pers. com.).

The last hypothesis can only be tested by further demagnetization to see if two components of magnetization can be recognized in the stable magnetization. Chemical demagnetization is one technique which might lead to the discovery of two components.

In any case, The VGP determined in this study is unacceptable for use in paleomagnetic correlation, and the use of pyrite bearing limestones, especially concretions, should be undertaken with extreme caution when doing paleomagnetic work.

CONCLUSIONS

The magnetization of the Huron Shale concretions consists of two components. A "soft" viscous component, which is effectively eliminated by AF demagnetization, and a "hard" post-depositional component carried by magnetite and controlled, either directly or indirectly, by the growth of the concretion.

Siderite was detected in the interior layer of the concretions studied on the basis of thermal demagnetization characteristics.

An extreme anisotropy of magnetic susceptibility exists in the concretions (30%), possibly due to growth of elongate paramagnetic pyrite crystals. Further study of the concretions, and other pyrite bearing limestones, should be undertaken to discover what effect the anisotropy has on the remanence in these rocks.

Chemical demagnetization should also be performed to see if the stable magnetization in the concretions consists of two components.

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